Tracking Systems and Applications

Stephen M. Lichten
Manager, Tracking Systems and Applications Section
818-354-1614
Stephen.Lichten@jpl.nasa.gov

James Zumberge
Deputy Manager, Tracking Systems and Applications Section
James.F.Zumberge@jpl.nasa.gov

Both at: Jet Propulsion Laboratory
Mail Code 238-638A
4800 Oak Grove Dr.
Pasadena, CA 91101

Jet Propulsion Laboratory, California Institute of Technology

JPL

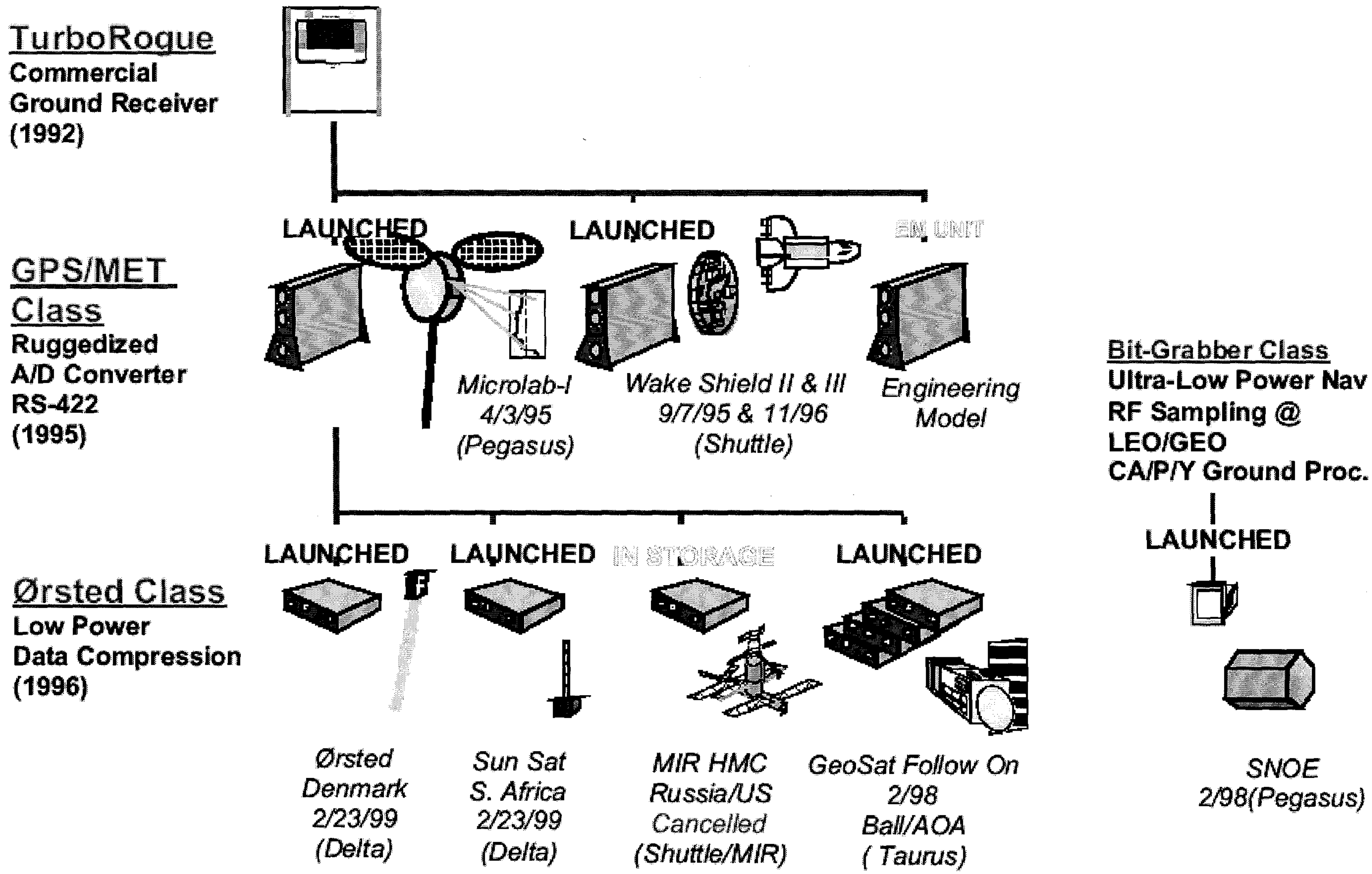
JPL's Tracking Systems and Applications Section (335)

- Technologies for precision spacecraft tracking, remote sensing, and science
  - GPS and spacecraft-spacecraft tracking systems technologies
  - Frequency and timing: advanced atomic clocks; oscillators and resonators
  - Quantum sciences and technologies
  - Radio interferometry, antenna arraying, and correlators
  - Earth and planetary science, astronomy, fundamental physics
- Sponsors: NASA, USAF, Navy, NRO, FAA, commercial partners
- Our Section is one of five in JPL's Telecommunications Science and Engineering Division
  - 128 employees (11 technical groups), 108 with B.S. or higher (74 Ph.D.'s)
    - 5 groups focused on GPS technology (two hardware and three analysis groups)
    - 2 groups focused on Frequency/Timing systems and quantum technologies
    - 3 groups focused on RF and optical interferometry
    - 1 group focused on solid Earth, atmospheric, and ocean science

Introduction (cont.)

- **Diverse section with technologists, specialists, and scientists provides a "cradle to grave" capability in GPS-based systems and applications**
  - Signal structure expertise; in-receiver algorithms and software; performance trades
  - Innovative GPS receiver design
  - Numerous spaceborne experiments and deployments
  - Orbit/trajectory estimation and user positioning algorithms& software
  - Precise spacecraft-spacecraft tracking systems
  - GPS global ground networks and automated data acquisition systems for precision ground and orbiting applications (operating on 24/7 basis)
  - Real-time and non-real-time applications; navigation/positioning; geolocation and time transfer; tropospheric and ionospheric science; gravity science; geophysics
- **Frequency and Timing unique core expertise**
  - Responsible for 24/7 operation of mission critical NASA/JPL frequency and timing subsystems in global Deep Space Network
  - Advanced atomic clock technology development; innovative oscillators and resonators; precision time and frequency measurements for NASA, USAF Research Lab and USNO
  - Underlying fields: quantum optics and electronics, laser cooling, fundamental physics
  - Presently building advanced space clocks for future GPS (Linear Ion Trap clock) and Space Station (Laser cooled clocks) deployments

Advanced GPS Receiver Technology (a)



Advanced GPS Flight Receivers/Transceivers (b)

<u>SAC-C Class</u>

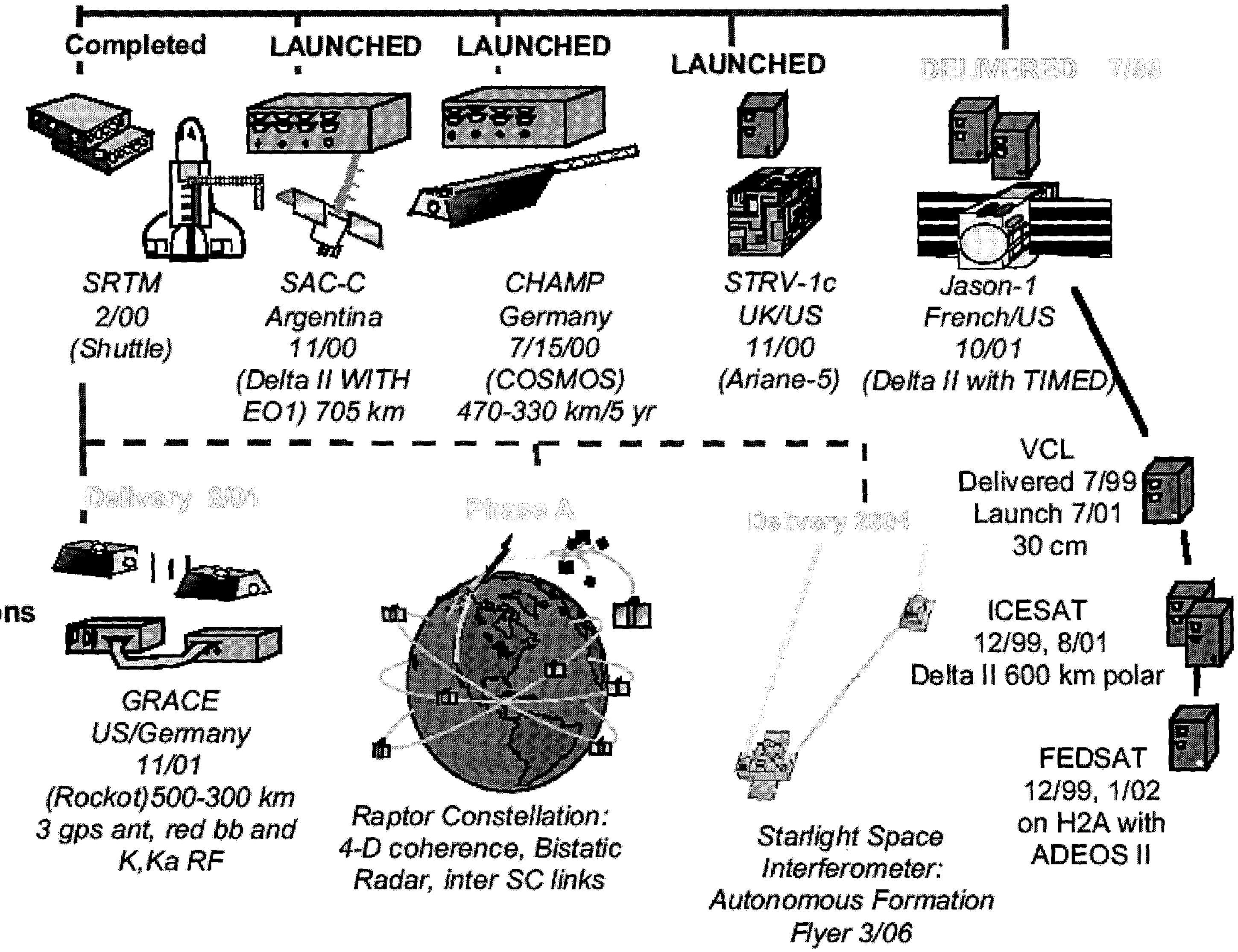
Hi- Performance PowerPC CPU
Lower Power
Multi-Antenna

<u>Raptor Class</u>

Additional Functions
Lower Power

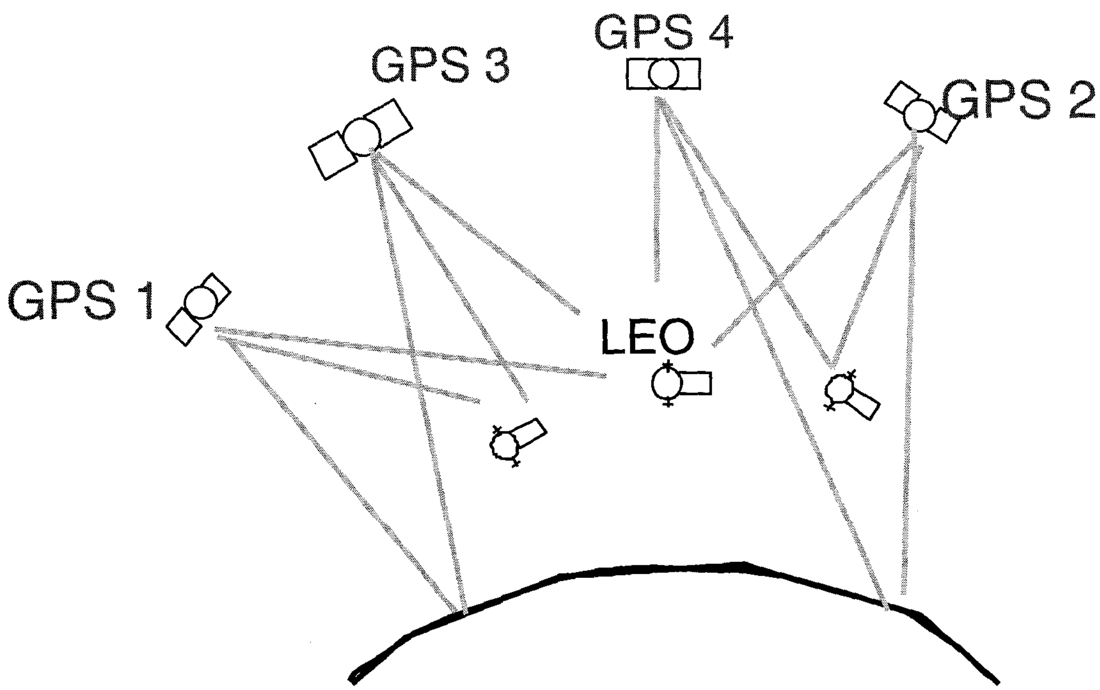
<u>And</u>

ST5
COSMIC 8 sats 1/03
LCAP, PARCS

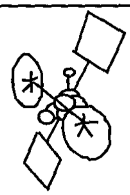


Precision LEO Positioning and Timing

- GPS tracking maintains constant and precise knowledge of relative spacecraft positions & clocks

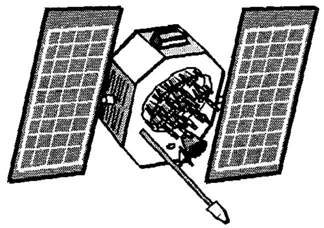


Demonstrated Orbit Accuracies With GPS



Geostationary
36000 km altitude
(TDRS, INMARSAT)

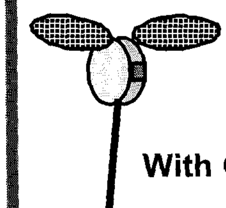
15 m
ground-based tracking



GPS

20000 km
altitude

8 cm (< 40-cm real-time)
operational automated processing

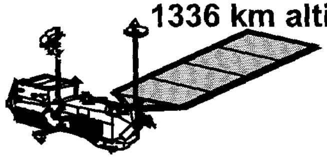


MicroLab/GPSMET
730 km altitude

With GPS < 10 cm

TOPEX/POSEIDON

1336 km altitude



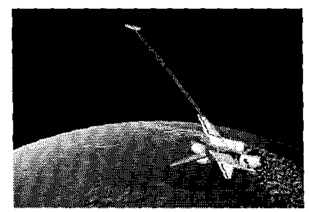
With GPS: < 2 cm radial accuracy

operational automated processing

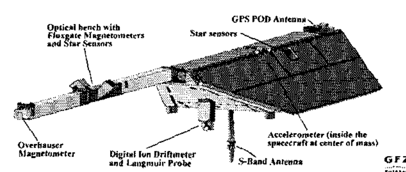
FUTURE GOAL: < 1-cm Orbit Accuracy for LEOs

Recent (2000) JPL Blackjack Flight GPS Receiver Results

Shuttle Radar Topography Mission (SRTM): 230-km alt
45-cm orbit accuracy

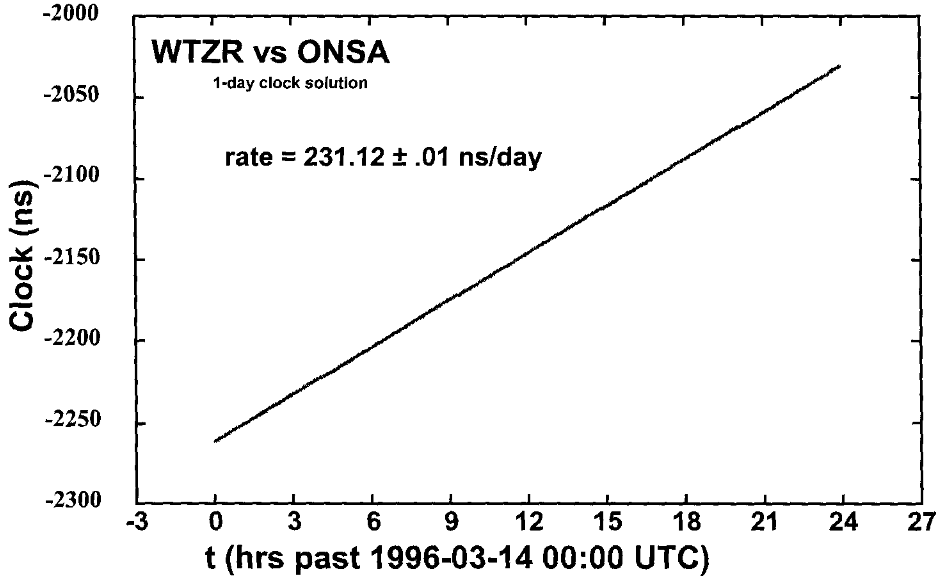


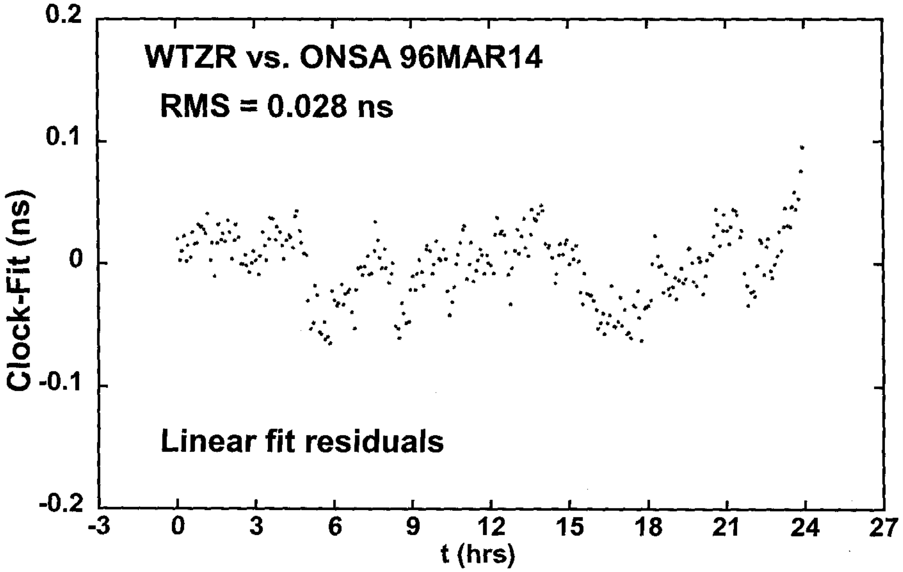
CHAMP: 470-km alt
< 10-cm orbit accuracy



SAC-C: 705-km alt
< 10-cm orbit accuracy

Ultra-Precise Time Transfer with GPS

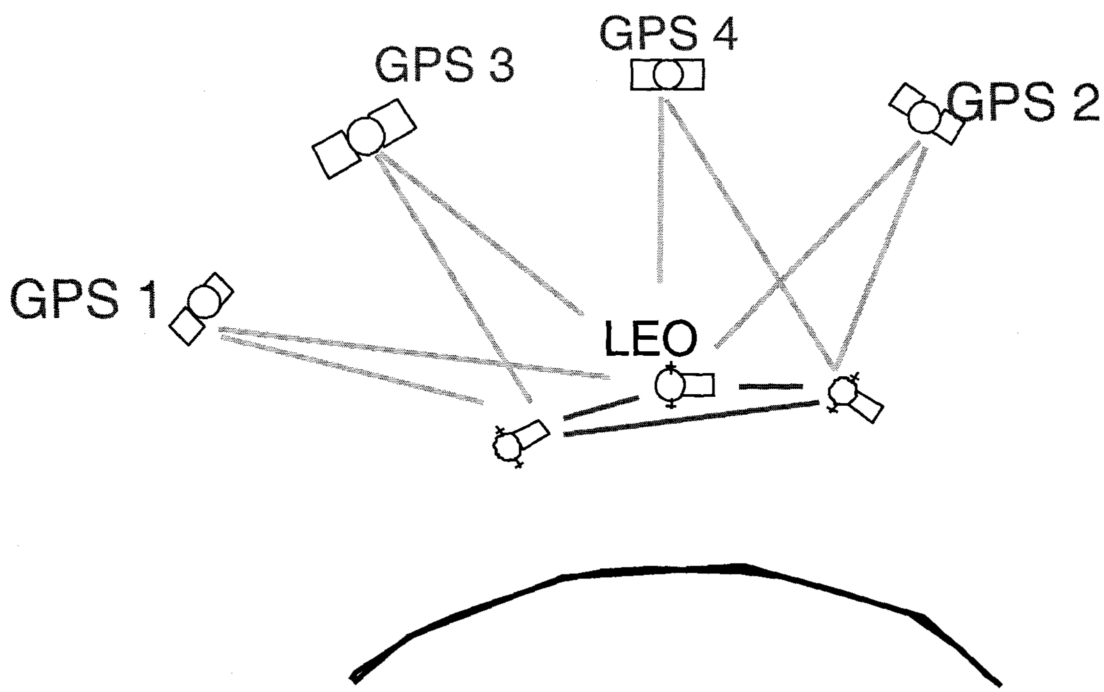




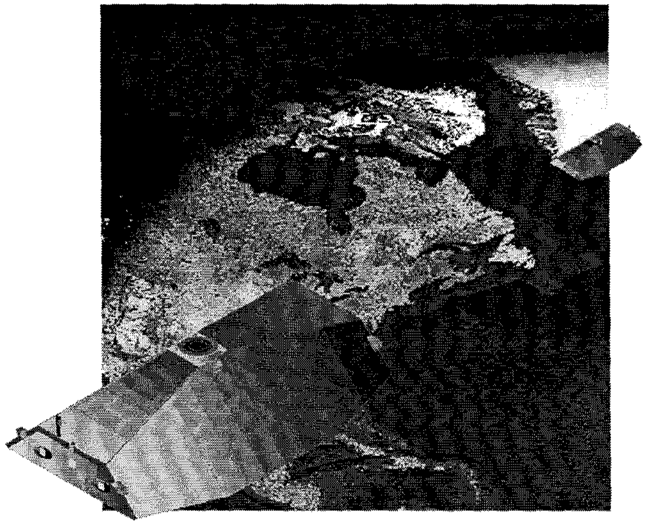
Linear fits to GPS-based clock estimates for pairs of masers worldwide (some separated by 1000's of km) show rms scatter of better than 30 picosec

Precision Spacecraft Positioning and Timing

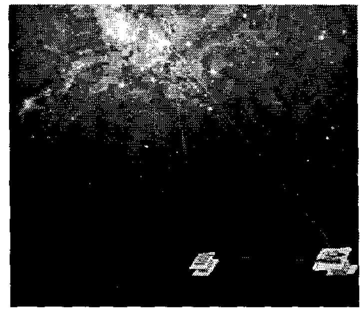
- GPS and/or LEO cross-link tracking maintain constant and precise knowledge of relative spacecraft positions & clocks



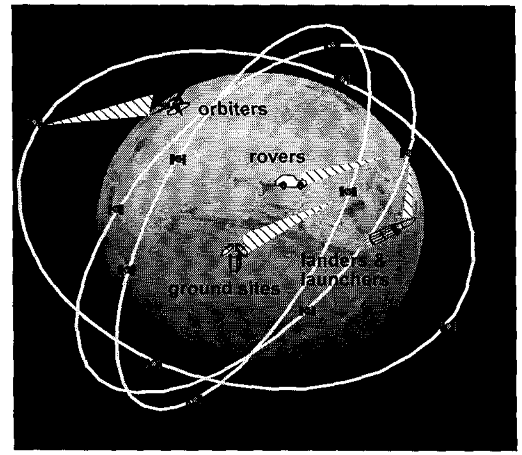
JPL Spacecraft Cross-Link Sensors Under Development for Space Deployments in 2001-2005



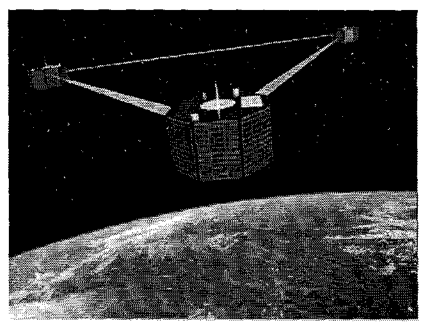
GRACE: JPL GPS Receiver with integrated camera and K-band spacecraft-spacecraft tracking, to provide 1-micron accuracy measurement of range change to improve knowledge of the Earth's gravity field <u>by several orders of magnitude</u>



Starlight: Precision (1-cm) formation flying



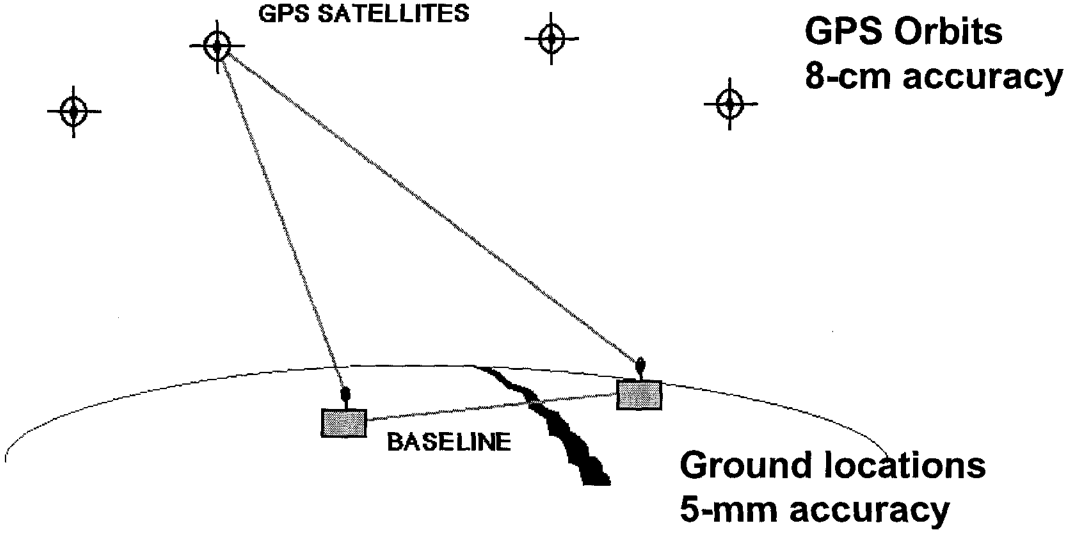
Mars Network Node: Integrated Navigation and Telecommunications

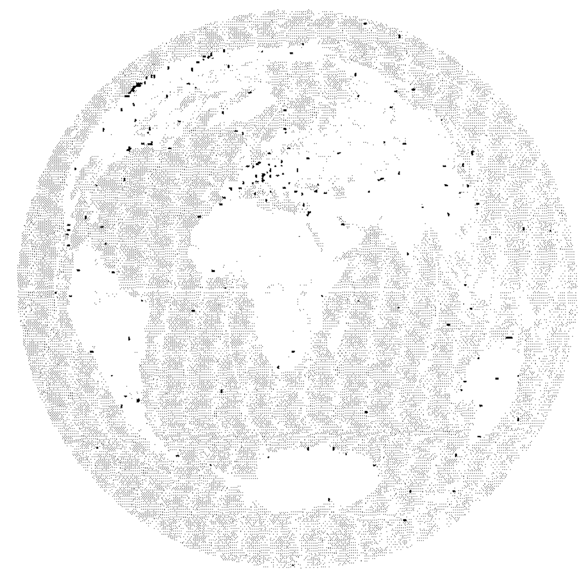


ST-5: GPS-based Constellation Communications and Navigation Transceiver (CCNT) for cross-link ranging and inter-spacecraft telecom in constellation of spacecraft in GEO-transfer elliptical Earth orbit

Global Positioning System (GPS) Measurements Applied to Geophysics and Natural Hazards

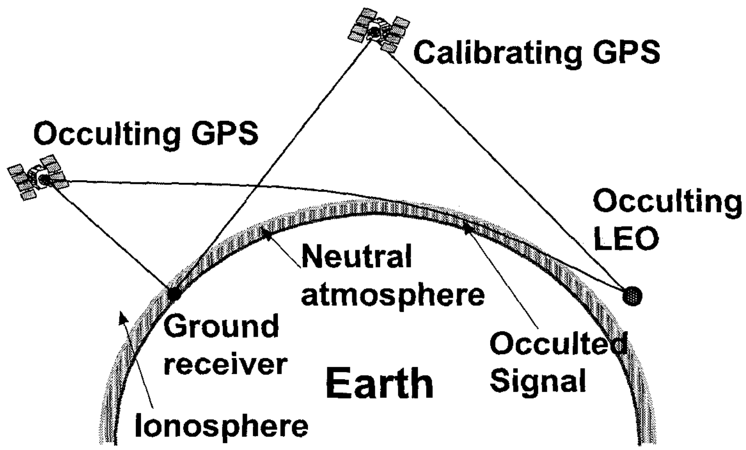
- NASA contributes about one-quarter of the > 200 GPS tracking stations in the International GPS Service (IGS) global network
- Analyses of their data is interpreted in terms of tectonic plate motions and geodynamics
- High density deployment of GPS sites contributes to the assessment of earthquake hazards (southern California map)



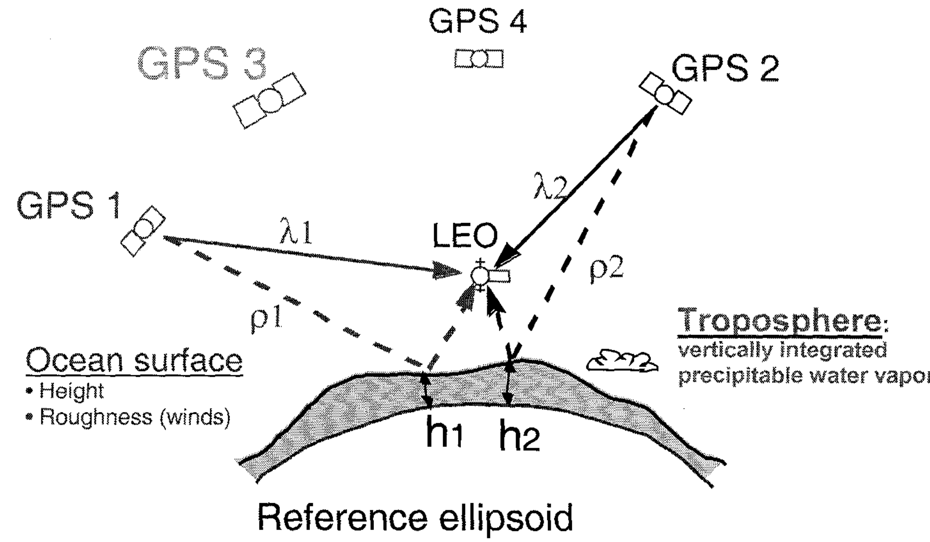


IGS Global Network

Novel Science Applications



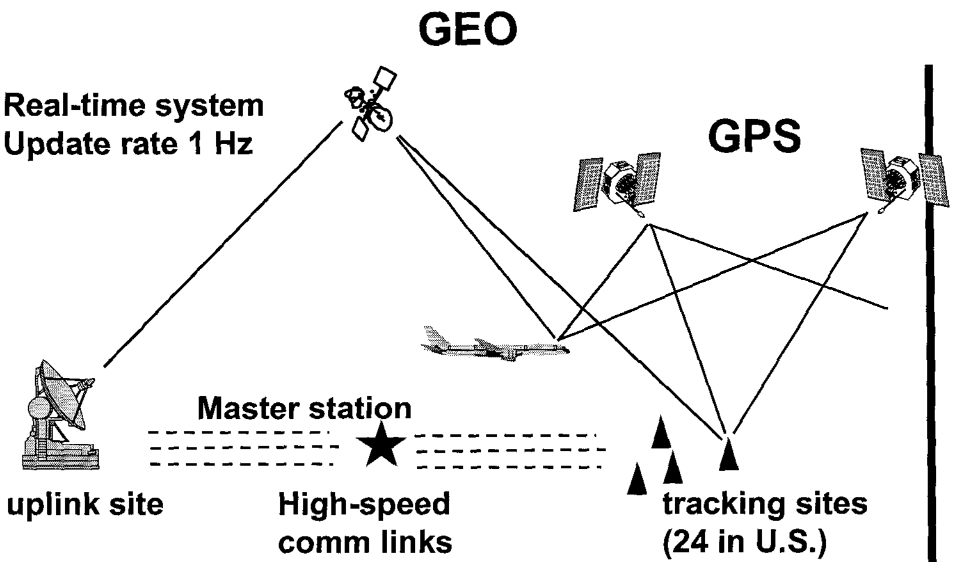
Atmospheric and Ionospheric Remote Sensing and Science



Bi-Static Ocean Reflectometry

California Institute of Technology

Task: GPS Wide Area Augmentation System (WAAS) Implementation

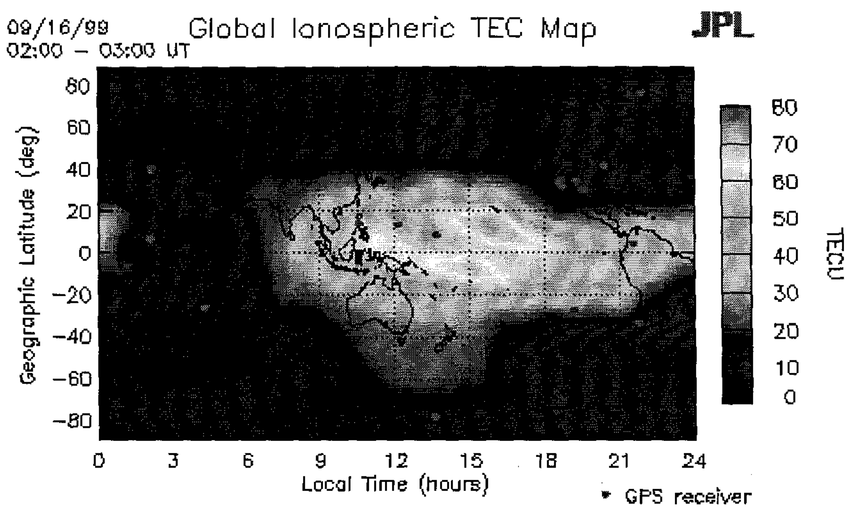


Task Purpose/Objectives:

- Deliver real-time software prototype to DOT/FAA for new GPS-based precision navigation system (WAAS) for aviation.

Major Products and Deliverables:

- Real-time software for GPS orbits, clocks, and ionosphere maps
- New GPS and safety algorithms



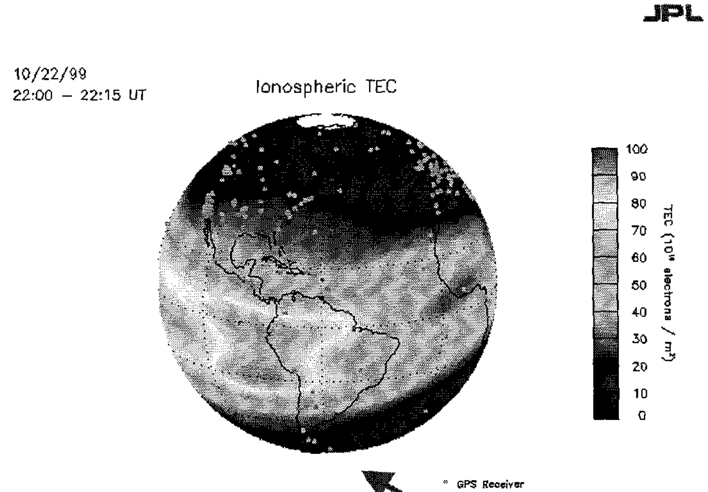
Customer Relevance:

- Improve airline navigation accuracy by orders of magnitude; enhance aviation safety in U.S.
- Save $12B+ in next decade in fuel and airport costs

NASA Relevance:

- Real-time, autonomous space navigation
- Onboard science data product generation
- Real-time natural hazard monitoring
- Pathfinder for the Mars Network Infrastructure.

Ionospheric Research At JPL



Goal: Mitigate impact of ionosphere on COMM, NAV and SURVEILLANCE systems

Capabilities:

- Accurately characterize ionospheric behavior
- Real-time input/output
- Tailored products

Technical Expertise:

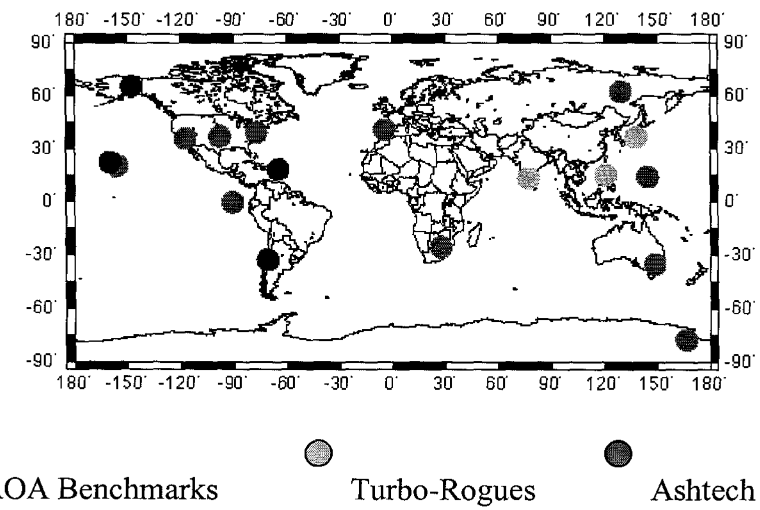
- Global snapshots of TEC in near real-time
- Data analysis for space-borne GPS receivers
  - Vertical electron density profiles & tomography
  - CHAMP, SAC-C & GRACE missions in FY'02
- Advanced global modeling development (GAIM)
  - Broad range of outputs (e^- density, winds, etc.)
  - Broad range of inputs (TEC, UV images, etc.)
- GPS Global Network
  - Real-time processing
  - Scintillation monitoring

Possible Joint Developments:

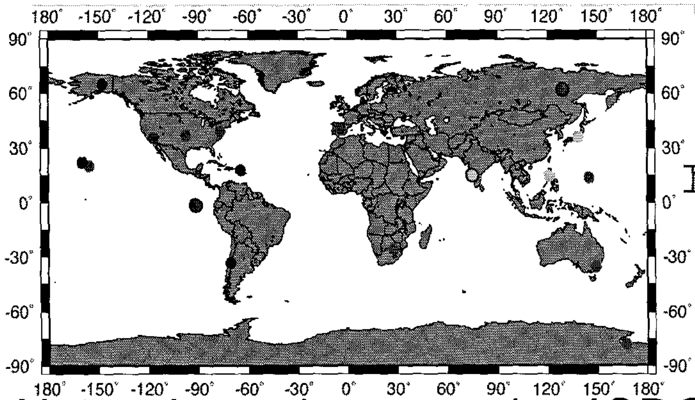
- Near real-time prediction of Total Electron Content
  - Accuracy study by Aerospace Corp.
  - Tailored development to further boost performance
- Joint analysis of space-borne GPS data
  - IOX instrument on PicoSat (L. 9/2001)
  - CORISS instrument on C/NOFS (L. 2003)
- Scintillation monitoring and prediction
- Improved global electron density specification
  - Tailor GAIM towards applications of interest
  - Accommodate new data types
- Transfer software

Precise Real-Time Global GPS Navigation

- **Established a global, real-time, GPS ground network**
  - **Real-time user accuracies: 8 cms RMS horizontal, 20 cms RMS**
    - **~ 10 times better than best available commercial and military systems**
  - **30-40 cms 3D (RSS) global GPS orbits, in real-time**
  - ***Winner of the 2000 NASA Software of the Year Award!***
  - **JPL's initial implementation utilizes Internet for communications; the system is being commercialized by Navcom who is adding GEOs to the network**
  - **NASA, DoD and commercial applications being studied, including:**
    - **RLV navigation**
    - **Automated LEO navigation and onboard science data product generation**



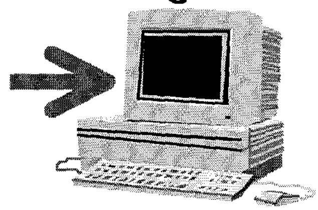
JPL's New Global Global Capability Supports 10-20 cm User Accuracy, Anywhere, Real-Time



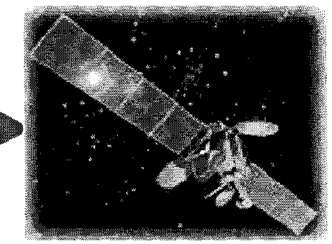
Network receivers running IGDG

Internet

JPL processing center running IGDG

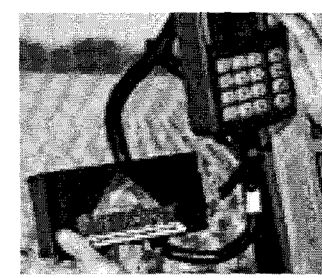


Broadcast



Internet

Broadcast



Remote user running IGDG

Revolutionary new capability:

decimeter real time positioning, anywhere, anytime

Capability		JPL's IGDG	Un-augmented GPS	Others (WADGPS services)
Coverage:	Global	Yes	Yes	No
	Seamless	Yes	Yes	No
	Usable in space	Yes	Yes	No
Accuracy:	Kinematic applications	0.1 m horizontal 0.2 m vertical	5 m	> 1 m
	Orbit determination	0.01 – 0.05 m (goal)	1 m	N/A
Dissemination method		Internet/broadcast	Broadcast	Broadcast
Targeted users		Dual-frequency	Dual-frequency	Single-freq.

For more info:
http://gipsy.jpl.nasa.gov/igdg

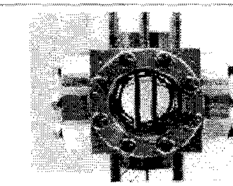
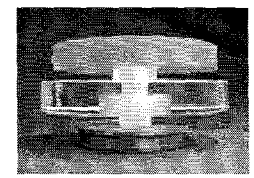
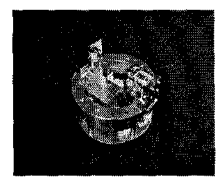
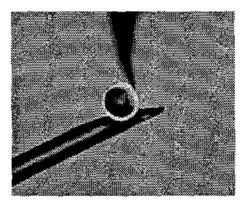
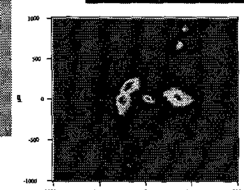
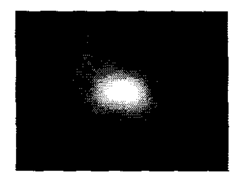
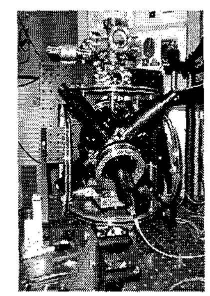
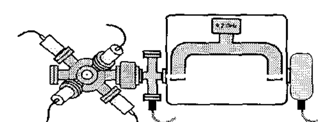
Frequency, Timing and Quantum Sciences and Technologies

Responsible for technology development, generation, and distribution of ultra-stable reference frequencies and synchronized timing signals for NASA's Deep Space Network (DSN).

R&D (Science and Technology) → Development Implementation → Evaluation Testing → Products & Service

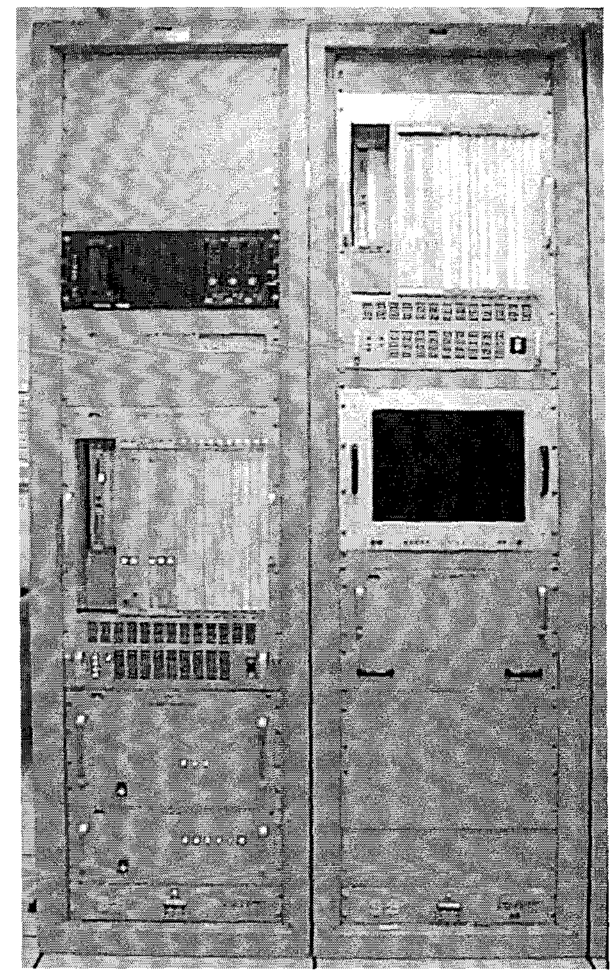
<u>Major research and technology development:</u>

- Linear Ion Trap Standards (LITS)
- *GPS LITS: Space version of LITS*
- Cryogenic Sapphire oscillators (CSO)
- Stabilized Optical Fiber microwave link (FODA)
- *Opto-Electronic Oscillator (OEO)*
- Micro spheres
- Trapped single ion experiment
- Laser Cooling and Atomic Physics (LCAP)
- *Space clocks - Primary Atomic Clock in Space (PARCS), Rubidium Atomic Clock Experiment (RACE)*
- *Bose-Einstein Condensate (BEC) generation*
- *Quantum Interferometer Gravity Gradiometer (QUIGG)*

Antenna Arraying and Interferometry

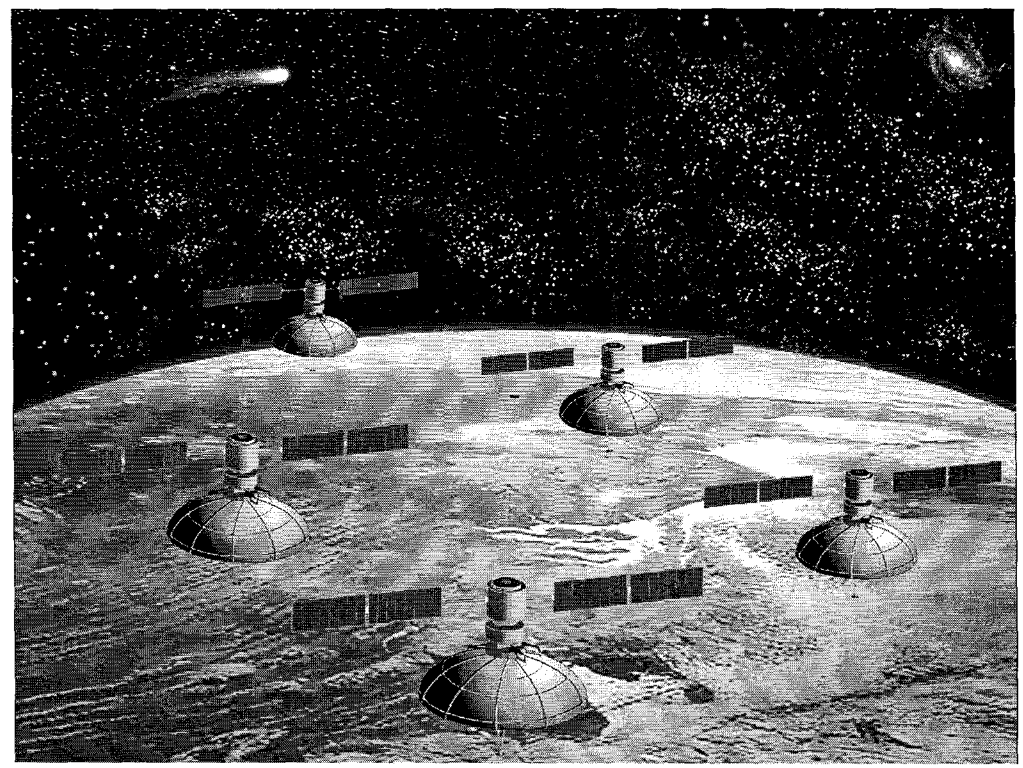
- Developed Low Rate (<250 sym/sec) Telemetry system arraying up to 7 antennas, for the Galileo Mission
- Completing a follow-on High Rate (6 Mega-sym/sec) Telemetry system arraying up to 8 antennas, for DSN
- Developed prototype Ka Band Array Feed and Signal Processing system for DSN 70m antenna enhancement
- VLBI (Very Long Baseline Interferometry) Correlators
  - Developed a narrowband (250 kHz) system in both H/W and later in S/W, primarily for spacecraft navigation
  - Developed a wideband (28-channel, 4 MHz, 4 station) H/W system used for Geodesy, Astrometry, Astronomy
  - Developed a real-time wideband (14-channel, 4 MHz, 2 station) correlator of same design as above system, together with a 800 Mbit/sec fiber optic channel for interconnecting antennas
  - Are in process of implementing a replacement wideband (16-channel, 16 MHz, 4 station) H/W system to be used for Space VLBI in addition to the above applications.
  - Developing a real-time wideband (8-channel, 16 MHz, 2 station) correlator of same design as above, with a 1 Gbit/sec fiber optic channel, to replace the above real-time system.



Advanced Microwave Sensing (Interferometric Imaging from Space)

- **JPL/Section 335 participated in study of advanced interferometric imaging capabilities from space platforms**
  - **Sponsored by NRL Code 7214 and another DoD organization**
- **Examined feasibility & assessed technical issues for such systems**

- **Study Goals**
  - Covertly detect, characterize, locate, and track all man-made earth-based and air-borne sources of RF energy and communications
  - Monitor & map all natural sources of RF energy and changes to them due to natural and human activities
  - Provide 24/7 day/night, all weather surveillance capability, precise geolocation, & penetration
- **Overview & Program Planning**
  - Develop concept arrays for detection and characterization of possible targets
  - Different array architectures were evaluated for performance, costs, and operational issues
  - Technology issues and tradeoffs were defined
- **Issues Affecting Space Operations**
  - A number of issues were investigated for orbit and cluster configurations, antenna and receiver designs, and communications and on-board data processing/compression



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